

SF2A 2005

F. Casoli, T. Contini, J.M. Hameury, and L. Pagani (eds)

THE PUZZLE OF THE SOFT X-RAY EXCESS IN AGN: ABSORPTION OR REFLECTION?

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Abstract. The 2-10 keV continuum of AGN is generally well represented by a single power law. However, at smaller energies the continuum displays an excess with respect to the extrapolation of this power law, called the “soft X-ray excess”. Until now this soft X-ray excess was attributed, either to reflection of the hard X-ray source by the accretion disk, or to the presence of an additional comptonizing medium, giving a steep spectrum. An alternative solution proposed by Gierliński and Done (2004) is that a single power law well represents both the soft and the hard X-ray emission and the impression of the soft X-ray excess is due to absorption of a primary power law by a relativistic wind. We examine the advantages and drawbacks of reflection versus absorption models, and we conclude that the observed spectra can be well modeled, either by absorption (for a strong excess), or by reflection (for a weak excess). However the physical conditions required by the absorption models do not seem very realistic: we would prefer an “hybrid model”.

1 Introduction

Now more than 50% of well studied Seyfert 1 galaxies and many quasars are known to possess absorbers (e.g., Blustin et al. 2005). One main issue is to explain the apparent change of slope in the overall X-ray spectrum at ~ 1 keV in Sy1s and QSOs. When fitting an observed X-ray spectrum with a power law plus absorption plus (eventually) the Compton reflection component plus (eventually) the iron line and (eventually) narrow spectral features, the model usually underpredicts the observed spectrum in the soft X-ray range. An additional component – a soft X-ray

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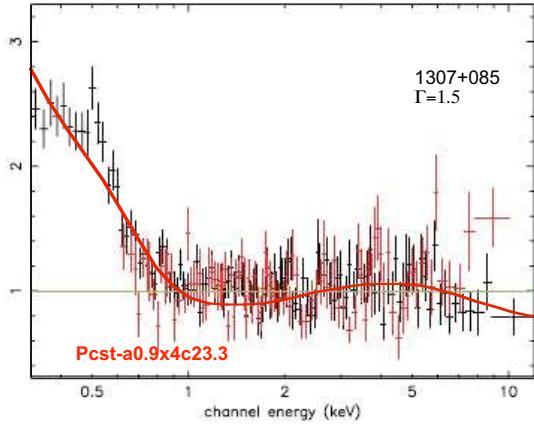


Fig. 1. Comparison between the observed X-ray spectra for PG 1307+085 (Piconcelli et al. 2005, Fig. 2) and the computed spectrum (arbitrary units) of a power law primary continuum $\alpha = 0.9$ absorbed by a constant total pressure slab ($\xi = 10^4$, $N = 2 \cdot 10^{23}$, $v/c = 0.2$, CGS units). The observed and computed spectra have been both divided by the observed power law of photon index $\Gamma = 1.5$ over the 2–10 keV range.

excess – is needed (Wilkes & Elvis 1987). Apart from an usual additional continuum or a strongly ionized reflection, this component is well modeled by absorption of an originally rather soft power law intrinsic spectrum due to an absorber having a random or bulk velocity of several thousands of km s^{-1} (Gierliński & Done 2004). We consider the advantages and drawbacks of the reflection vs. absorption models (Chevallier et al. 2005), using our code TITAN (Dumont et al. 2003).

2 Results

Gierliński & Done (2004) modeled the X-ray spectrum of the Narrow Line Seyfert 1 PG 1211+143 by a steep power law continuum between 0.1 and 20 keV, absorbed by an ionized slab of constant density. Note that the observed spectrum is smeared by a large (Gaussian) velocity dispersion $v/c = 0.2$ in order to get a “quasi-continuum” with no narrow features. This high velocity can be due to an accelerated outflow, or to a disk wind dominated by Keplerian motion and produced very close to the black hole.

We have computed the absorption spectra – no corresponding emission and the absorbing medium covers completely the primary source of radiation – for a grid of constant density models. Any small variation of the parameters, like the column-density N , the ionization parameter $\xi = L/nR^2$ (L is the luminosity of the primary source, n and R are the hydrogen number density and the distance from the primary source, respectively, of the medium at the illuminated surface), or the slope α of the primary continuum, would induce a strong variation on the shape of the X-ray spectrum.

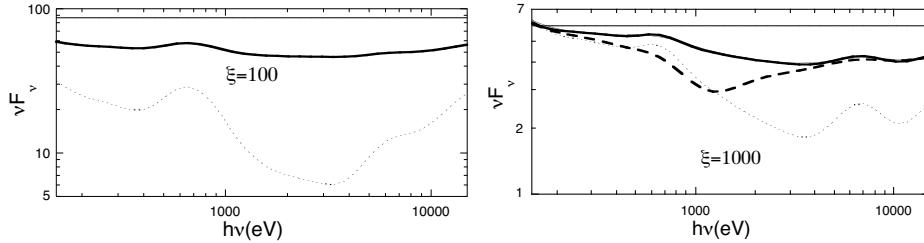


Fig. 2. Computed spectra (arbitrary units) for thick reflection models (left: $\xi=100$, right: $\xi=1000$). The components shown are the primary continuum (straight lines), the reflection spectrum (thin dots), half sum of reflection plus primary continuum (thick lines) which may be directly “observed” or absorbed by a constant total pressure slab $N = 10^{22}$, $\xi = 100$ (CGS units), with a dispersion velocity $v/c = 0.2$ (thick dashes).

Such a variation is not observed from one object to the other. It is more appropriate to assume that the absorbing medium is in total – gas and radiation – pressure equilibrium owing to the short dynamical time scale needed to reach again an equilibrium (less than one day for $R \sim 10 R_G$, where $R_G = GM/c^2$, and $M \sim 10^7 M_\odot$). The thickness of the slab cannot then exceed a maximum value for a given ξ , due to thermal instabilities. A consequence is the existence of a “maximum absorption trough”, which cannot be exceeded.

Figure 1 shows as an exemple the comparison of the X-ray spectrum of PG 1307+085 (Piconcelli et al. 2005) with that obtained with an absorbing slab of constant total pressure. This spectrum is well fitted, considering that the narrow emission feature around 0.5 keV – the OVII complex – must be provided by another emitting region.

Absorption models are not very satisfactory from a physical point of view. Owing to its large column density ($\sim 3 \cdot 10^{23} \text{ cm}^{-2}$), the wind implies too massive outflows (near the Eddington limit). Both the wind and the accretion models require an additional UV emission, which has to be provided by a geometrically thin accretion disk. The coexistence of a spherical accretion flow at about $25 R_G$ and a thin disk seems quite artificial. So we come back now to the “traditional” reflection models, including a “cold” accretion disk emitting the UV, surrounded by a hot corona emitting X-rays which are reflected by the disk (Haardt & Maraschi 1993). Figure 2 shows two examples of reflection models, with $\xi = 100$ and 1000. The soft X-ray excess (thick line) almost disappears when the reflection spectrum (thin dots) is added to the primary continuum (thin line). Either ξ is small and the reflection spectrum displays a strong X-ray excess, but it is negligible as compared to the primary one; or ξ is large, and the reflection spectrum is comparable in flux to the primary one, but it has a small X-ray excess. A strong excess requires to hide the primary continuum (Fabian et al. 2002, Crumley et al. 2005).

Since both the absorption and the reflection models seem inadequate, we propose an “hybrid model”, including the traditional reflection model, plus a high

velocity absorbing medium with a modest thickness. As shown by Fig. 2 (right panel), the small soft X-ray excess displayed by the reflection model (thick line) is increased when it is absorbed by such a wind (thick dashes) and becomes comparable to the observations. The mass outflow rate is thus 30 times smaller than in the previous absorption model.

3 Conclusion

Absorption models could account for some strong soft X-ray excesses, but require a kind of “fine tuning” in order to constrain the 1 keV trough, which otherwise could have any strength (e.g., constant density models). We have suggested a medium in total – gas and radiation – pressure equilibrium, which leads to a maximum intensity of the trough, as well as a “universal” shape of this maximum trough, due to the thermal instability mechanism. A complete grid of constant total pressure models, very demanding in computation time, is necessary to pursue this study. In the absorption model, either a thick accretion flow, or a relativistic wind is required. None of them seem realistic from a physical point of view, and moreover both require an additional source of UV emission, like a geometrically thin accretion disk. On the other hand, the traditional reflection models involving a hot corona emitting X-rays which are reflected by a cold disk cannot account for the observations, unless the X-ray source is hidden from our view. Therefore we favor an “hybrid” model, where the primary UV-X source could be produced by a disk-corona system, and then absorbed by a modest relativistic wind.

A. C. Gonçalves acknowledges support from the *Fundaçao para a Ciéncia e a Tecnologia*, Portugal, under grant no. BPD/11641/2002. Part of this work was supported by the Laboratoire Européen Associé Astrophysique Pologne-France.

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